

CAN ELECTRON BY COMPTON SCATTERING BE CONSIDERED AS A TYPICAL DETECTOR OF THE PHOTON PROPAGATION

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Abstract

In this work we consider a possibility that Compton scattering can be considered as a typical measurement (detection) procedure within which electron behaves as the measuring apparatus, i.e. detector (pointer) of the propagation of the photon as the measured object. It represents a realistic variant of the old gendanken (though) experiment (discussed by Einstein, Bohr, Dirac, Feynman) of the interaction between the single photon as the measured object and a movable mirror as the measuring apparatus, i.e. detector (pointer). Here collapse by measurement is successfully modeled by spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) representing an especial case of the spontaneous (non-dynamical) breaking (effective hiding) of the dynamical symmetries. All this is full agreement with all existing experimental data and represents the definitive solution of the old problem of "micro" theoretical foundation of measurement or old problem of the foundation of quantum mechanics as a local (luminal) physical theory.

1 Introduction

In this work we shall consider a possibility that Compton scattering can be considered as a typical measurement (detection) procedure within which electron behaves as the measuring apparatus, i.e. detector (pointer) of the propagation of the photon as the measured object. It represents a realistic variant of the old gendanken (thought) experiment (discussed by Einstein, Bohr, Dirac, Feynman [1]-[5]) of the interaction between the single photon as the measured object and a movable mirror as the measuring apparatus, i.e. detector (pointer). Here collapse by measurement will be successfully modeled by spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) [6]-[9] representing an especial case of the spontaneous (non-dynamical) breaking (effective hiding) of the dynamical symmetries [10]-[12]. All this is full agreement with all existing experimental data and represents the definitive solution of the old problem of "micro" theoretical foundation of measurement or old problem of the foundation of quantum mechanics as a local (luminal) physical theory.

2 Problem of the "micro" theoretical foundation of quantum measurement

In the remarkable discussions between Einstein and Bohr on the conceptual foundation of the quantum mechanics [1], [2] and later, by other authors [3]-[5], a very useful, simple gedanken (thought) experiment has been considered detailedly. This experiment represents the interaction between the single photon propagating toward a half-silvered mirror (or equivalently a diaphragm with two slits) and this half-silvered mirror. In the first of two complementary situations half-silvered mirror is "fixed" (by a screw mechanism) or "non-movable". In this situation there is practically none energy-momentum exchange between the photon and half-silvered mirror or more precisely there is no any entanglement (correlation) between energy-momentum quantum states of the photon and half-silvered mirror. It admits that interaction between the photon and half-silvered mirror can be consistently described by the product of the unitary quantum dynamical operator acting deterministically on the initial photon quantum state and unitary quantum dynamical operator acting deterministically on the initial half-silvered mirror quantum state. Final photon quantum state represents superposition between reflected and transmitted photon quantum state that according to unitary symmetry of the quantum dynamics stands conserved during time. This superposition can be later unambiguously detected by an additional measuring apparatus, i.e. detector. Final half-silvered mirror quantum state is, practically, equivalent to the initial.

In the other of two complementary situations half-silvered mirror is "movable" or "non-fixed" (screw mechanism is out of the function). In this situation energy-momentum exchange between the photon and half-silvered mirror occurs or more precisely entanglement (correlation) between energy-momentum quantum states of the photon and half-silvered mirror occurs. For this reason dynamical interaction between the photon and half-silvered mirror must be presented by a super-systemic unitary quantum dynamical operator that cannot be consistently described by (or consequently separated in) the product of the unitary quantum dynamical operator acting on the initial photon quantum state and unitary quantum dynamical operator acting on the initial half-silvered mirror quantum state [13], [14]. Nevertheless, this super-systemic unitary quantum dynamical operator acts deterministically on the initial quantum state of the super-system, photon+half-silvered mirror. It yields the final quantum state of the super-system that represents an entangled quantum state (super-systemic superposition). First term of this entangled quantum state is proportional to the product of the transmitted photon quantum state and quantum state of the half-silvered mirror without any change of its initial energy-momentum. Second term of this entangled quantum state is proportional to the product of the reflected photon quantum state and quantum state of the half-silvered mirror that absorbed an amount of the energy-momentum. But whole entangled quantum state of the super-system cannot be within standard quantum mechanical formalism [11]-[13] presented as the product of the quantum states of the sub-systems, photon and half-silvered mirror. Roughly speaking quantum super-system in the entangled quantum state cannot be separated in its sub-systems within standard quantum mechanical formalism.

It seems intuitively that interaction between photon and "movable" half-silvered mirror must correspond to a typical measurement procedure within which half-silvered mirror representing a typical measuring apparatus, i.e. detector, or simply - pointer, points out is photon representing the measured quantum object reflected or transmitted. But, as it is well-known on the basis of the experimental data, in such measurement single photon must be detected either as the reflected or as the transmitted with equivalent probabilities. In other words, according to unambiguous experimental data, photon is finally, i.e. after the realized measurement, described exactly (not

approximately) by a statistical mixture but not by a superposition of the reflected and transmitted quantum state. It seemingly implies that the super-system, photon+half-silvered mirror, must be finally, i.e. after the realized measurement exactly (but not approximately) described by a statistical mixture of the quantum states but not by an entangled quantum state. It implies too that measurement of the photon propagation by the half-silvered mirror as the detector-pointer cannot be exactly presented as the any unitary quantum dynamical interaction between the single photon and half-silvered mirror [13]. In this way there is unambiguously a "discrete" distinction between deterministic unitary symmetric (that conserves superposition) quantum dynamics and its breaking, simply called collapse, by measurement. (This distinction can not be consistently removed even in the "romantic" Everett many-world or relative state interpretation [15] of the standard quantum mechanical formalism. In the Everett interpretation collapse is formally changed by "branching of the universe". But it, exactly speaking, can be consistent only by reduction of the set of all quantum mechanical variables and standard quantum mechanical formalism that contradicts to experimental facts. There is other possibility that Everett interpretation be consistent which needs a non-unitary extension of the quantum dynamics that goes over standard quantum mechanical formalism.)

Einstein suggested [1], [16] that this and other similar problems can be solved under supposition that unitary symmetric (that conserves superposition) quantum mechanical dynamics is incomplete and that it must be completed or extended by some additional, non-unitary dynamical terms, simply called hidden variables. In this case, or within hidden variables theories [17], [18] collapse by the measurement can be considered as a dynamical (by additional hidden variables non-unitary dynamical terms) exact breaking of the incomplete quantum dynamical unitary symmetry. It is conceptually analogous to other situations in the physics with dynamical breaking of the incomplete dynamical symmetries, e.g. by the parity symmetry breaking by weak nuclear interactions [12]. But as it has been theoretically proved by Bell [19] and experimentally checked by Aspect et al [20], [21] any hidden variable theory that tend to reproduce existing experimental data must be necessarily super-luminal or non-local. It represents an extremely physically non-plausible characteristic (which implies a non-removable distinction between hidden variables theories and quantum field theories and string theories). It is very important to be pointed out that quantum dynamics only, without its extension by hidden variables, is not super-luminal, i.e. non-local, but luminal, i.e. local, since Bell analysis does not refer on the usual, non-extended quantum dynamics.

Bohr [1], [2] suggested a phenomenological, "macroscopic", simply called Copenhagen theory of the measurement in full agreement with all experimental data without any non-locality or super-luminality (since it does not need any extension of the unitary quantum dynamics). Within Copenhagen theory half-silvered mirror is described somewhat effectively-approximately "classically". Precisely, it is supposed ad hoc, phenomenologically, that interaction between the photon and half-silvered mirror, in the case when "macroscopic", with "classical dynamics" half-silvered mirror behaves effectively-approximately as the pointer, must be effectively-approximately considered as the non-reductable under statistical limits predicted by Heisenberg's uncertainty relations. Without this "classical domains" or when interaction between the photon and half-silvered mirror is described exactly unitary quantum dynamically there is no collapse at all and super-system, photon+half-silvered mirror, is exactly described by the entangled quantum state. In other words collapse is not an absolute (exact) but only relative (effective-approximate) phenomenon, while unitary (that conserves superposition) quantum dynamics is absolute (exact).

Bohr pointed out [1], [2] that such conclusion is conceptually analogous to situation that

appears within theory of relativity: "Before concluding I should still like to emphasize the bearing of the great lesson derived from general relativity theory upon the question of physical reality in the field of quantum theory. In fact, notwithstanding all characteristic differences, the situation we are concerned with in these generalizations of classical theory presents striking analogies which have often been noted. Especially, the singular position of measuring instrument in the account of quantum phenomena, just discussed, appears closely analogous to the well-known necessity in relativity theory of upholding an ordinary description of all measuring processes, including sharp distinction between space and time coordinates, although very essence of this theory is the establishment of new physical laws, in comprehension of which we must renounce the customary separation of space and time ideas. The dependence of the reference system, in relativity theory, of all readings of scales and clocks may even be compared with essentially uncontrollable exchange of the momentum or energy between the objects of measurement and all instruments defining the space-time system of the reference, which in quantum theory confront us with the situation characterized by the notion of complementarity. In fact this new feature of natural philosophy means a radical revision of our attitude as regards physical reality, which may be paralleled with the fundamental modification of all ideas regarding the absolute character of physical phenomena, brought about general theory of relativity." [2].

According to Bohr unitary symmetry of the quantum dynamics corresponds to Lorentz or Riemann symmetry of the especial or general relativistic dynamics, while collapse corresponds to the ether both of which can be considered as the effective-approximate local effects without exact global meaning. Riemann symmetry of the relativistic dynamics simply means that the relativistic dynamics has the invariant form in all referential frames in the space-time with general Riemannian metric. None of these frames is absolutely dynamically preferred globally, i.e. in the whole space. But locally, in any sufficiently small domain of the Riemann space-time, characteristic "absolute" referential frame with Euclidian metric is effectively-approximately preferred by Newtonian classical mechanical approximation of the general relativistic dynamics. Analogously, Bohr supposed, unitary symmetry of the quantum dynamics simply means that the quantum dynamics has the invariant form in all bases of the Hilbert space representing quantum referential frames. None of these bases is absolutely preferred globally, i.e. in whole Hilbert space. Collapse by measurement of some observable with characteristic eigen basis prefers this basis, i.e. quantum referential frame. It can be supposed that such preference is local and relative since it must be realized by approximate classically reduced or localized description of the measuring apparatus, i.e. detector-pointer.

Obviously, Copenhagen measurement theory implies or moreover needs further development of the "microscopic", more precise quantum form. It is conceptually similar to situation by superfluidity where Landau "macroscopic" theory of the superfluidity implies its characteristic "microscopic", more precise quantum form done by Bijl, Boer and Feynman. Really, following some ideas of Ne'eman [22], Damnjanovic [23] showed formally-mathematically but without an immediate physical explanation, that collapse can be considered as a Landau continuous phase transition.

An important step by the development of the "microscopic" theory of measurement has been done within so-called approximationistic theory suggested by many authors [24], [25]. Within this theory it is observed and pointed out that, by real measurement, detector-pointer quantum states (correlated unambiguously by quantum dynamics to quantum states of the measured observable of the object) can be always approximated by wave packets. As it is well-known [3] wave packet represents such approximation within which quantum dynamics can be globally (in whole space)

reduced in the classical mechanical dynamics while quantum dynamical state can be globally (in whole space) reduced in the classical mechanical particle. Domains of the accuracy of this approximation are predicted by Heisenberg uncertainty relations. Precisely, under limits predicted by Heisenberg uncertainty relations wave packet approximation or classical dynamics cannot be consistently applied in distinction from exact quantum dynamics that can be applied without any limits. Further, detector-pointer wave packets that are initially strongly interfering, become, during interaction between measured object and detector-pointer, weakly interfering. It means that after ending of the quantum dynamical interaction between object and detector-pointer, distance between centums (or average values of the coordinates) of any two wave packets is larger than one wave packet coordinate standard deviation (under supposition that standard deviation of the coordinate is practically equivalent for all wave packets). In this way quantum dynamical interaction between object and detector-pointer can be simplifiedly considered as a restitution of the entangled state whose terms, i.e. sub-terms representing detector-pointer wave packets do a typical Landau continuous phase transition (with distance between wave packets centums as the variables and wave packets coordinates standard deviation as the order parameter in full agreement with Heisenberg uncertainty relations) from initial strongly interfering toward final weakly interfering state. For a macroscopic, i.e. sufficiently massive detector-pointer, for which dissipation of the wave packets represents an extremely long-lasting period mentioned phase transition will be satisfied in an analogous extremely long-lasting period, and vice versa. In the way almost all Copenhagen demands are founded "microscopically" quantum precisely.

However, main Copenhagen demands or collapse as the statistical effective breaking of the unitary quantum dynamical symmetry stands "microscopically" unformalized. Namely, it is not hard to see that approximationistic theory suggest a phase transition from strongly interfering in the weakly interfering terms within the entangled quantum states, but not a phase transition from entangled in the mixed quantum state. Solution of this problem has been suggested by Pankovic et al [6]-[9] that proved that collapse by measurement will be successfully modeled by spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) representing an especial case of the general formalism of the spontaneous (non-dynamical) breaking (effective hiding) of the dynamical symmetries[10]-[12].

3 General formalism of the spontaneous (non-dynamical) breaking (effective hiding) of the dynamical symmetry

General formalism of the spontaneous (non-dynamical) breaking (effective hiding) of an exact dynamical symmetry [10]-[12] can be presented simply in the following way.

Any complete dynamics, i.e. dynamical equation, holds real existing, exact solution, i.e. exact dynamical state with the same symmetry as well as the equation.

But, in some cases, this exact solution can be presented in the explicit form (by usual simple functions) neither theoretically nor experimentally. For this reason different approximate procedures or theories must be used, mostly small perturbation theories corresponding to expansion in the Taylor series.

If this series globally converges, i.e. if it converges in the whole space of the dynamical states, approximate solution converges to exact solution.

But, if this series globally diverges, i.e. if it diverges in the whole space of the dynamical states, approximate solution does not exist. Nevertheless, exact solution exactly exists but it cannot be

presented by non-existing global approximate solution.

However, such situations are possible when approximate solution globally diverges but when it locally converges. It means that approximate solution can converge in some discretely separated parts of the space of all dynamical states, which corresponds to decrease or breaking of some dynamical symmetry. Then global approximate solution does not exist again, or, formally speaking, global approximate solution is approximate dynamically non-stable. In this sense given global solution is unobservable too. But, for reason of the existence of local domains of approximate dynamical stability, given "initial" global non-stable approximate solution can turn (or it can be projected) spontaneously, i.e. without any additional dynamical influence, in some of many discretely separated domains of the approximate dynamical stability. After transition in given local domain, approximate solution with decreased or broken symmetry, becomes dynamically presentable or observable. Then it represents "final" local stable approximate solution. It is very important to be pointed out that complete transition (projection) process cannot be presented or described by global non-stable approximate dynamics too. Describable is only its end, i.e. "final" local stable approximate solution. Also, for reason of this local approximate dynamical stability inverse process, i.e. transition from local stable approximate solution in global non-stable approximate solution cannot be realized spontaneously.

In this way actual transition from global non-stable in local stable dynamical state has fundamental probabilistic-statistical character. Also, here, a-priori probabilities must be dependent from "initial", global non-stable approximate dynamical state as well as from corresponding "final" local stable approximate dynamical states. On the other hand, mentioned transition corresponds to actualization of given a-priori probabilities, i.e. to transition of given a-priori in the a-posteriori probabilities one of which becomes one, and all other zero.

Here again it can be repeated and pointed out that given actualization of the probabilities cannot be modeled deterministically for reason of the global non-stability of the approximate dynamics. It, also, corresponds to statement that any local stable approximate dynamical state represents (projects) the same global non-stable approximate dynamical state. In other words, here dynamical-deterministic evolution, from the initial, global non-stable approximate dynamical state in the final, local stable approximate dynamical state, does not exist, in difference from theories with dynamical breaking of the symmetry.

We can consider famous example of the spontaneous breaking of the gauge symmetry within Weinberg-Salam theory of the electro-weak interaction. Weinberg-Salam theory holds exact gauge symmetric solution of corresponding exactly gauge symmetric quantum field theory dynamical equation. But this exact solution cannot be obtained in an explicit form at all. For this reason mentioned solution must be presented by some approximate theories, e.g. small perturbation theory within low energetic sector. Such approximate solution of the dynamical equation globally diverges (it does not converge for any value of the field) representing globally dynamically unstable and non-describable state. Especially it diverges in the zero field point with non-zero energy (for this reason given point is called false vacuum). But, approximate solution converges locally, i.e. at least in some non-zero field points (simply, but asymmetrically translated in respect to symmetric zero field point) with minimal energies (for this reason given field points are called real vacuums). In this way, within small perturbation approximation it can be consistently supposed that a dynamically non-describable, principally probabilistic, i.e. statistical transition from globally non-stable in one locally stable dynamical state occurs. Such transition, of course, corresponds to spontaneous (non-dynamical) gauge symmetry breaking.

Fictitious exact, dynamical breaking of the gauge symmetry, i.e. exact dynamical description

of the translation from false in the real vacuum would imply non-renormalizability and physical non-plausibility of Weinberg-Salam theory. Vice versa, remarkable t'Hooft proof of the renormalizability of Weinberg-Salam theory is concretely done for an especially chosen calibration. Only according to exactly unbroken gauge symmetry given proof is satisfied generally, in any calibration (since one calibration can be appropriately gauge transformed in any other), even if proof satisfaction in the general case is not so obvious.

4 Collapse by quantum measurement as the spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding)

Now we can consider collapse by quantum measurement as the spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding).

As it is well-known [3] wave packet approximation can be obtained by Taylor expansion of the exact Ehrenfest quantum dynamics of the average values of observables (analogous to Schrödinger equation). More precisely, suppose that zero order Taylor expansion term is significantly larger than second order Taylor expansion term (corresponding to Heisenberg uncertainty relation) and other higher order Taylor expansion terms (first order term is always exactly equivalent to zero). Then this series is convergent and can be approximately reduced in its zero order term. It represents formally a Newtonian classical mechanical dynamical form of the wave packet as a particle model. Namely, here absolute average values of all observables become significantly larger than corresponding statistical deviations, so that, roughly speaking, wave character of the quantum phenomena effectively disappears.

It is well known too that higher (than first) order Taylor expansion terms grows up in respect to zero term during time that represents so-called wave packet dissipation. When second order term (Heisenberg uncertainty relation) becomes comparable with zero order term (absolute average values of observables) Taylor series becomes divergent or at least discretely different from wave packet approximation. Then approximate wave packet dynamics or classical mechanical dynamics become completely non-applicable. Nevertheless, exact Ehrenfest quantum dynamics of the average values of observables stands exactly satisfied in this case too.

For microscopic systems convergence and applicability of the wave packet approximation become very quickly broken. For this reason classical mechanical dynamics cannot be consistently applied for description of the dynamics of micro-systems. For macroscopic systems convergence and applicability of the wave packet approximation can be extremely large. For this reason classical mechanics can be excellently applied for description of the dynamics of macro-systems.

Consider now a basis whose quantum states can be approximately considered as the weakly interfering (in previously determined sense) wave packets. Then the following theorem, according to general definition of the wave packet and weakly interfering wave packets approximation, can be proved very simply [6]-[9]:

Superposition of the weakly interfering wave packets does not represent any wave packet. This superposition, within wave packet approximation, becomes spontaneously (non-dynamically) broken and turns out (in the dynamically non-describable way) in some of the wave packets with corresponding probability. However, exactly quantum mechanically, this superposition stands conserved.

It can be demonstrated at the following simple example. Suppose that there is a superposition

$|s\rangle$ of two weakly interfering wave packets $|1\rangle$ and $|2\rangle$ with equivalent superposition coefficients. According to the definition of the wave packet it is satisfied $\langle 1|x|1\rangle \gg \Delta x_1$ and $\langle 2|x|2\rangle \gg \Delta x_2$ where $\langle 1|x|1\rangle$ and $\langle 2|x|2\rangle$ represent the coordinate average value or center of the first and second wave packet (we shall suppose that both centers are positive and that first center is larger than second) while Δx_1 and Δx_2 represent the coordinate standard deviation of the first and second wave packet. According to the condition of the weak interference of the wave packets it is satisfied approximately $\langle s|x|s\rangle \simeq \frac{1}{2}(\langle 1|x|1\rangle + \langle 2|x|2\rangle)$ and $\Delta x_s \simeq \frac{1}{2}(\langle 1|x|1\rangle - \langle 2|x|2\rangle)$, where $\langle s|x|s\rangle$ represents the coordinate average value in the superposition $|s\rangle$ while Δx_s represents the coordinate standard deviation in the superposition $|s\rangle$. As it is not hard to see condition $\langle s|x|s\rangle \gg \Delta x_s$ is not satisfied in the general case. For example, for $\langle 1|x|1\rangle = 2\langle 2|x|2\rangle$ it follows $\langle s|x|s\rangle \simeq \frac{3}{4}\langle 2|x|2\rangle$ and $\Delta x_s \simeq \frac{1}{4}\langle 2|x|2\rangle$ or $\langle s|x|s\rangle \sim \Delta x_s$.

It means that within wave packet approximation systemic or super-systemic superposition of the weakly interfering wave packets represents globally (in the whole usual space) unstable classical dynamical state, even if, of course, exactly quantum mechanically this superposition is dynamically globally (within whole Hilbert space) stable state. On the other hand, within wave packet approximation, any wave packet in the systemic or super-systemic superposition represents locally (within domain of the standard deviation in respect to its coordinate center) stable classical dynamical state. In this way condition for realization of the spontaneous (non-dynamical) superposition breaking is satisfied completely, according to general theory of the spontaneous (non-dynamical) symmetry breaking (effective hiding). It implies that superposition of the weakly interfering will be spontaneously (non-dynamically) broken and turn out (in the dynamically non-describable way) in some of the wave packets with corresponding probability. However, exactly quantum mechanically, this superposition stands conserved. It, of course, represents previously mentioned theorem.

As it is not hard to see theorem on the spontaneous (non-dynamical) breaking (effective hiding) of the quantum dynamical unitary symmetry (superposition) refers on the any superposition, systemic or super-systemic, i.e. entangled quantum state. It means that this spontaneous superposition breaking can, under necessary approximation condition of the weakly interfering wave packets, occur in the entangled quantum state of the measured quantum object and measuring apparatus, i.e. detector-pointer. Also, it is not hard to see that all proved characteristics of this spontaneous superposition breaking correspond to necessary characteristics of the collapse. For this reason can be consequently and consistently concluded that collapse represents the spontaneous (non-dynamical) breaking (effective hiding) of the quantum dynamical unitary symmetry (superposition) by measurement as the mentioned continuous Landau phase transition.

Finally, it can be pointed out that concept of the collapse as the spontaneous (non-dynamical) unitary quantum dynamical symmetry (superposition) breaking (effective hiding) considers unitary quantum dynamical evolution as the unique exact form of the change of the quantum state during time. For this reason it admits quite naturally that quantum mechanics be a luminal or local physical theory.

In this way problem of the "micro" theoretical foundation of quantum measurement is solved definitely. In other words everybody can simply understand quantum mechanics. It represents the local (luminal) theory with exactly unitary (that conserves superposition or that has invariant form in any basis, i.e. quantum referential frame in Hilbert space) quantum dynamics of the quantum states. Also, it admits that the collapse by measurement can be "micro" theoretically founded as the continuous Landau phase transition with spontaneous (non-dynamical) breaking (effective hiding) of the quantum dynamical unitary symmetry (superposition) when superposition

satisfied approximately condition of the weakly interfering wave packets. That is all and nothing more is necessary.

5 Collapse as the spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) by interaction between the photon and half-silvered mirror

Now we shall precisely describe collapse as the spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) by interaction between the photon and half-silvered mirror.

In the initial time moment, i.e. before quantum dynamical interaction between photon, P, and "movable" half-silvered mirror, HSM, (where word "movable" implies the quantum well controlled energy-momentum exchange between P and HSM), super-system, photon+half-silvered mirror, $P + HSM$, is described by the following non-entangled quantum state

$$|P + HSM(0) \rangle = |P\mathbf{p}(0) \rangle |HSM0(0) \rangle. \quad (1)$$

Here $|P\mathbf{p}(0) \rangle$ represents the quantum state of P propagating with momentum \mathbf{p} , while $|HSM0(0) \rangle$ represents the quantum state of HSM that can be approximated by a wave packet in the rest (without momentum).

Immediately after unitary quantum dynamical interaction between P and HSM in some time moment τ , super-system $P + HSM$, is exactly described by the following entangled quantum state

$$|P + HSM(\tau) \rangle = a|P\mathbf{p}(\tau) \rangle |HSM0(\tau) \rangle + b|P\mathbf{p} - \Delta\mathbf{p}(\tau) \rangle |HSM\Delta\mathbf{p}(\tau) \rangle. \quad (2)$$

Here a and b represent the superposition coefficients (whose values are determined by HSM characteristics) satisfying unit norm condition $|a|^2 + |b|^2 = 1$. Also, first normalized term at the right hand of (2) represents the transmitted P (with unchanged momentum) and HSM in the rest (without momentum) while second normalized term at the right hand of (2) represents the reflected photon (with diminished momentum $\mathbf{p} - \Delta\mathbf{p}$) and HSM in the quantum state that can be approximated by wave packet moving with momentum $\Delta\mathbf{p}$.

Expression (2), under introduced suppositions and conditions, is satisfied practically generally. But if exchanged momentum $\Delta\mathbf{p}$ between P and HSM is small so that in the time moment τ wave packets $|HSM0(\tau) \rangle$ and $|HSM\Delta\mathbf{p}(\tau) \rangle$ are not weakly interfering conditions for realization of the collapse as the spontaneous superposition breaking are not satisfied. In this case described unitary quantum dynamical interaction between P and HSM (2) cannot be consistently reduced in the measurement.

Meanwhile, in the opposite ("complementary") case, when exchanged momentum $\Delta\mathbf{p}$ between P and HSM is sufficiently large, so that in the time moment τ wave packets $|HSM0(\tau) \rangle$ and $|HSM\Delta\mathbf{p}(\tau) \rangle$ are weakly interfering, all conditions for realization of the collapse as the spontaneous superposition breaking are satisfied. In this case described unitary quantum dynamical interaction between P and HSM (2) can be consistently approximately reduced (by the collapse as the spontaneous superposition breaking) in the measurement that HSM as the measuring apparatus or detector-pointer realizes at P as the measured quantum object. Within this approximation entangled quantum state (2) can be effectively changed by the following mixture of the non-entangled quantum states

$$\begin{aligned} \rho_{P+HSM}(\tau) = & |a|^2 |P\mathbf{p}(\tau) \rangle \langle P\mathbf{p}(\tau)| |HSM0(\tau) \rangle \langle HSM0(\tau)| \\ & + |b|^2 |P\mathbf{p} - \Delta\mathbf{p}(\tau) \rangle \langle P\mathbf{p} - \Delta\mathbf{p}(\tau)| |HSM\Delta\mathbf{p}(\tau) \rangle \langle HSM\Delta\mathbf{p}(\tau)| \end{aligned} \quad (3)$$

First term at right hand of (3) describes situation of the appearance of the transmitted P and HSM in rest with probability $|a|^2$, while second term at the right hand of (3) describes reflected P and moving HSM with probability $|b|^2$.

Especially, it can be pointed out that even if HSM wave packets are weakly interfering but not non-interfering statistical mixture of the quantum states of P corresponding to (3) is

$$\rho_P(\tau) = |a|^2 |P\mathbf{p}(\tau) \rangle \langle P\mathbf{p}(\tau)| + |b|^2 |P\mathbf{p}(\tau) - \Delta\mathbf{p}(\tau) \rangle \langle P\mathbf{p}(\tau) - \Delta\mathbf{p}(\tau)|. \quad (4)$$

This expression and their physical meaning (an exact effective de-coherence between the transmitted and reflected photon) is satisfied even in case when $|P\mathbf{p}(\tau) \rangle$ and $|P\mathbf{p} - \Delta\mathbf{p}(\tau) \rangle$ are strongly interfering. For this reason, seemingly, collapse on P described by (4) seems as an "absolute and exact quantum" phenomenon. But of course, collapse on P is really only effectively exact quantum phenomenon according to previous discussions.

It can be observed that changing of the value of dynamically exchanged momentum between the photon and half-silvered mirror a Landau continuous phase transition between situation without measurement (small value of the exchanged momentum) and with measurement (large value of the exchanged momentum) can be realized in principle. It represents a clear proposition of the theory of measurement as the spontaneous superposition breaking that can be experimentally checking in principle.

However, it is not hard to see that in the realistic cases, i.e. for macroscopic, massive half-silvered mirror, value of the dynamically exchanged momentum between the photon and mirror will be always small so that situation corresponding to measurement will practically never appear. This problem, at the first sight, would be solved by diminishing of the dimension (mass) of half-silvered mirror. But with smaller and smaller dimensions of the half-silvered mirror there is larger and larger dynamical or thermodynamical influence of the environment at the half-silvered mirror. For this reason some authors, e.g. Zurek [26], Joos, Zeh [27], suggested so-called environmentalistic theory of measurement according to which collapse represents the effect of the non-existence of the really isolated quantum systems. This theory is not consistent with standard quantum mechanical formalism and leads implicitly toward hidden variables theories, on the one hand. On the other hand environmentalistic theory of measurement contradicts unambiguously to recent experimental data [28], [29] according to which there is possibility of the real isolation of the quantum systems from the external thermal influences. Mentioned data point out unambiguously that (with neglectable external influences) entangled quantum state exist not only in the micro, but also in the meso or macro domains. (Especially in [29] it is experimentally unambiguously proved that a classical quasi-macroscopic oscillator can be controllably quantum dynamically transferred, by absorption of single phonon, from the initial, ground in the final, first excited quantum state while. Also, in the same experiment, between the initial and final state this oscillator is entangled with a quantum qubit.) In other words these data proved practically unambiguously that unitary quantum dynamics represents the universal characteristic.

However, condition of the weakly interfering wave packets on the macroscopic or at least mesoscopic systems is to this day experimentally yet unrealized for reason of the extremely large technical difficulties. For example, such type experiment suggested by Marshal et al [30] and interpreted by Pankovic et al [6] needs extremally small temperature of the environment.

But our theory of the measurement as the Landau continuous phase transition with spontaneous superposition breaking, as it is not hard to see, can be experimentally checked not only at the macroscopic and mesoscopic but at the microscopic systems too. In further work we shall suggest a simple example of the experimental checking of our theory some microscopic systems interacting mutually analogously to the photon and "movable" half-silvered mirror. Precisely, we shall discuss a variant of the well-known experiment of the Compton scattering of the photon at the electron.

6 Collapse as the spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) by Compton scattering of the photon on the electron

Consider the following experimental scheme. Single photon, P, emitted from a source, S, propagates with momentum \mathbf{p} toward a fixed half-silvered mirror, HSM. After unitary quantum dynamical interaction with HSM P is described by the following superposition state

$$|P\mathbf{p}\rangle = \alpha|PT\mathbf{p}\rangle + \beta|PR\mathbf{p}'\rangle. \quad (5)$$

Here α and β represents the superposition coefficients that satisfy unit norm condition $|\alpha|^2 + |\beta|^2 = 1$. Quantum state $|PT\mathbf{p}\rangle$ describes P transmitted through HSM with unchanged momentum \mathbf{p} , while quantum state $|PR\mathbf{p}'\rangle$ describes P reflected by HSM in some direction so that $|\mathbf{p}| = |\mathbf{p}'|$.

Suppose further that transmitted P will be Compton scattered on an electron, e, in the rest according to usual, well-known experimental procedure.

Suppose finally that there is a filter, F. It, without any momentum change, transmits photon scattered in the direction determined by angle ϕ and absorbs P scattered in any other direction. Mentioned angle ϕ and F position can be chosen arbitrary.

In this way, after Compton scattering and filtration, sub-ensemble of the non-absorbed P and correlated e, precisely corresponding super-system $P + e$, is described by the following entangled quantum state, or by super-systemic superposition

$$|P + e\rangle = \alpha(\phi)|PT\mathbf{p}\rangle|e0\rangle + \beta(\phi)|PR\mathbf{p}(\phi)\rangle|e\Delta\mathbf{p}(\phi)\rangle. \quad (6)$$

Here $\alpha(\phi)$ and $\beta(\phi)$ represent the renormalized (on the mentioned sub-ensemble) superposition coefficients that satisfy unit norm condition $|\alpha(\phi)|^2 + |\beta(\phi)|^2 = 1$. Here $|PR\mathbf{p}(\phi)\rangle$ describes P Compton scattered in direction determined by ϕ with changed momentum $\mathbf{p}(\phi)$ while $|e\Delta\mathbf{p}(\phi)\rangle$ describes e that propagates with momentum $\Delta\mathbf{p}(\phi) = \mathbf{p} - \mathbf{p}(\phi)$ after collision with P.

Wavelength λ of P before Compton scattering is determined by de Broglie relation

$$\lambda = \frac{h}{|\mathbf{b}|} \quad (7)$$

where h represents the Planck constant. Then variation of (7), caused by P momentum diminishing by Compton scattering, yields

$$\Delta\lambda = -\frac{h}{|\mathbf{b}|^2}|\Delta\mathbf{b}(\phi)| = -\lambda\frac{|\Delta\mathbf{b}(\phi)|}{|\mathbf{b}|} \quad (8)$$

or

$$\frac{\Delta\lambda}{\lambda} = -\frac{|\Delta\mathbf{b}(\phi)|}{|\mathbf{b}|}. \quad (9)$$

For

$$|\Delta\mathbf{b}(\phi)| \ll |\mathbf{b}| \quad (10)$$

(9) implies

$$\frac{\Delta\lambda(\phi)}{\lambda} \ll 1 \quad (11)$$

It means that there is no significant increase of the P wavelength by Compton scattering. It implies that entangled quantum state (6) can be approximated by the following non-entangled quantum state

$$|P + e(\phi) \rangle \simeq (\alpha(\phi)|PT\mathbf{b} \rangle + \beta(\phi)|PR\mathbf{b}(\phi) \rangle)|e0 \rangle \quad (12)$$

within which P is described by the quantum superposition state

$$|P(\phi) \rangle \simeq (\alpha(\phi)|PT\mathbf{b} \rangle + \beta(\phi)|PR\mathbf{b}(\phi) \rangle). \quad (13)$$

This superposition can be detected by an additional measurement.

Namely, experimental scheme can include two total (fixed) mirrors MT and $MR(\phi)$. First mirror directs P described by $|PT\mathbf{b} \rangle$ toward a detector, D, while second mirror directs P described by $|PR\mathbf{b}(\phi) \rangle$ toward D. D can detect the interference between $|PT\mathbf{b} \rangle$ and $|PR\mathbf{b}(\phi) \rangle$ if it exists so that it can detect superposition (13).

For

$$|\Delta\mathbf{b}(\phi)| \simeq |\mathbf{b}| \quad (14)$$

(9) implies

$$\frac{\Delta\lambda(\phi)}{\lambda} \simeq 1. \quad (15)$$

It means not only that there is a significant increase of the P wavelength by Compton scattering but also that P propagation before this scattering and after this scattering must be necessarily de-coherent (since $\Delta\lambda(\phi)$ as the wavelength perturbation by scattering becomes almost equivalent to the P wavelength before scattering). In this case $\Delta\lambda(\phi)$ can be considered as the minimal coordinate interval $\Delta\mathbf{q}(\phi)$ within which P is detected by Compton scattering and it, according to (14), (15), yields

$$|\Delta\mathbf{q}(\phi)||\Delta\mathbf{p}(\phi)| \simeq h \quad (16)$$

representing, of course, Heisenberg coordinate-momentum uncertainty relation.

Moreover, for (14), (15), entangled quantum state (6) cannot be approximated by the non-entangled quantum state (12). In this case later detection (by MT, $MR(\phi)$ and D representing a typical sub-systemic measurement [14]) will detect the absence of the superposition (13) and existence of the P mixed state

$$\rho_P(\tau) = |\alpha(\phi)|^2|PT\mathbf{p} \rangle \langle PT\mathbf{p}| + |\beta(\phi)|^2|PR\mathbf{p}(\phi) \rangle \langle PR\mathbf{p}(\phi)|. \quad (17)$$

It, before detection, does not exist quantum exactly, or, before detection it represents only a formal second kind mixture [14]. Namely, before detection quantum super-system $P + e$ is described by entangled quantum state (6) that does not admit separation of the super-system in its sub-systems. However, within domain of the approximation necessary for realization of the spontaneous superposition breaking it can be consistently stated that P has been effectively described by mixed

state (17) immediately after interaction (Compton scattering) with e and before later detection (by MT, $MR(\phi)$ and D). It simply means that here Compton scattering can be considered as the measurement process within which e behaves as the detector-pointer of the photon propagation. (Later detection by MT, $MR(\phi)$ and D only repeat results of the previous measurement by Compton scattering.)

As it is well-known, by Compton scattering it is satisfied

$$\Delta\lambda(\phi) = 2\lambda_{ce} \sin^2\left(\frac{\phi}{2}\right) \quad (18)$$

where $\lambda_{ce} = 2.410^{-12}m$ represents the e Compton wavelength. When ϕ increases from 0 toward π then $\Delta\lambda(\phi)$ (18) increases from 0 toward $2\lambda_{ce} = 4.8^{-12}m$. Then maximal P wavelength for which (15) can be satisfied and mixed state (17) detected equals

$$\lambda_{max} \simeq 2\lambda_{ce} = 4.8^{-12}m. \quad (19)$$

But then condition (11) concretized, for example, in the following way

$$\frac{\Delta\lambda(\phi_{max})}{\lambda_{max}} \simeq \frac{1}{100} \quad (20)$$

implies that maximal P wavelength variation for which superposition (13) can be detected equals

$$\Delta\lambda(\phi_{max}) = \frac{1}{100}\lambda_{max} \simeq 0.510^{-14}m \quad (21)$$

and, according to (18), that corresponding maximal angle equals

$$\phi_{max} \simeq 0.1 = 5.7^\circ. \quad (22)$$

As it is not hard to see predicted parameters (19)-(22) are in the domains of the recently development experimental devices and techniques for detection of the ultra small de Broglie wavelengths [31]-[33].

Thus in here suggested experimental scheme it can be started with P wave length λ_{max} (19) and with initial angle of the P Compton scattering ϕ_{max} (22). In this situation, according to standard quantum mechanical formalism and our "micro" theory of the measurement it can be expected that later detection will really detected P superposition state (13).

Further, in the next steps of the experiment realization, P Compton scattering angle ϕ can be done larger and larger. In the intermediate situations, with neither small nor large P scattering angle, momentum and wavelength change by Compton scattering, as it has been pointed out by Feynman [5], a "mixture" of the P superposition (13) and P mixed state (17) will appear, in full agreement with standard quantum mechanical formalism. Precisely, on the statistical ensemble of the detected P, two different statistical sub-ensembles will appear. In the first statistical sub-ensemble any P will be described by superposition (13), while in the second statistical-sub-ensemble any P will be described by mixed state (17). None homogeneous statistical ensemble, within which any P would be described by an intermediate state between the superposition and mixture, will not appear really. These intermediate situations imply also from our "micro" theory of the measurement but they represent the effects of the high order so that they go over basic intention of this work. In any case when P Compton scattering angle ϕ becomes larger and larger

first (superposition) statistical sub-ensemble becomes smaller and smaller while second (mixture) statistical sub-ensemble becomes larger and larger too.

Finally, for sufficiently large P Compton scattering angle and sufficiently large P wavelength change proportional to λ_{max} there is practically only one P statistical ensemble within which any P is described by the mixed state (17).

7 Conclusion

In conclusion we shall shortly repeat and point out the following. In this work we consider a possibility that Compton scattering can be considered as a typical measurement (detection) procedure within which electron behaves as the measuring apparatus, i.e. detector (pointer) of the propagation of the photon as the measured object. It represents a realistic variant of the old gendanken (thought) experiment (discussed by Einstein, Bohr, Dirac, Feynman) of the interaction between the single photon as the measured object and a movable mirror as the measuring apparatus, i.e. detector (pointer). Here collapse by measurement will be successfully modeled by spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) representing an especial case of the spontaneous (non-dynamical) breaking (effective hiding) of the dynamical symmetries. All this is full agreement with all existing experimental data and represents the definitive solution of the old problem of micro theoretical foundation of measurement or old problem of the foundation of quantum mechanics as a local (luminal) physical theory. Everybody can simply understand quantum mechanics, even Homer Simpson.

8 References

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